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Rice Processing Effects on Milling Yields, Protein Content and Cooking Qualities

Ramachandra M. R. Rao, William H. James, Arthur F. Novak and Ismail Bin Shamsudin[1]

INTRODUCTION

Rice, which is the chief daily staple in the diet of more than half the world's population, is an important agricultural commodity in Louisiana. In the most densely populated areas of the tropics, rice is more than just a carbohydrate food; there it is also the chief source of dietary protein.

When harvested, the rice grain is encased in an easily removable protective hull or husk. Inside the hull is a kernel of brown rice, so-called because of the dark bran layers covering the endosperm. The kernel with part of the bran removed is called undermilled rice, and when practically all of the bran layers and germ are removed it is known as milled rice. Brown rice contains more protein, minerals, and vitamins than milled rice, but when large amounts are consumed daily, as is the custom in the Orient, it is reported to cause digestive disturbances (*27*).[2] Milled rice is more attractive in appearance, requires less time to cook, and keeps better in storage than brown and undermilled rice. Furthermore, in humid environments, both brown and undermilled rice easily become rancid (*17, 27*).

Rice as harvested in the fields is known as rough rice, or paddy. The rough rice is milled to remove the hull, bran, and germ with minimum breakage of the kernels. The milling process generally consists of four separate operations: (a) cleaning the field run rough rice to remove contaminants and other foreign materials; (b) shelling the cleaned rough rice to remove the hulls; (c) scouring the brown rice to remove the coarse outer layers of bran, aleurone layer, and germ; and (d) grading the mixture of whole and broken milled kernels according to size classes known as head rice, broken, screenings, and brewers rice (*38, 47, 53*). Highly milled rice is white to creamy in color. It is high in starch and is an excellent high energy food but is low in vitamins (*17*). Rough rice is often subjected to parboiling, which consists of processing with heat and water before the husks are removed. Parboiling makes it possible to utilize a lower grade of rice

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[2]Italic numbers in parentheses refer to Bibliography, page 48.

and produce a higher quality product with less breakage during milling. Parboiled rice retains vitamins and minerals during subsequent operations of milling, washing, and cooking. Among other advantages resulting from parboiling rough rice are greater ease in milling, resistance to insect and pest attack during storage, and better retention of shape during cooking (*53, 54*).

Briefly, the parboiling process involves soaking the rough rice in either cold or hot water in cement or metal tanks for two to three days to increase the moisture content of the grain. The excess water is then drained off and the rice is placed in metal cylinders containing one or more perforated steam pipes. Steam is blown into the rice until the hulls are opened slightly. The parboiled rice is then removed from the cylinders, thoroughly dried in the sun or by artificial means, and milled. Several highly mechanized commercial parboiling processes have been developed in recent years (*12, 38*).

Parboiled rice differs from raw white rice in that the former possesses a light to dark yellow color and a distinctive "fermented" flavor and odor. The color, flavor, and odor are influenced by processing conditions. When produced under poorly controlled conditions, the flavor and color are strong, but under strict quality control the color may be very light and the flavor mild. The distinct color and flavor of parboiled rice is a deterrent for many who eat white rice, despite the high nutritive value of the parboiled product (*21*). Improvement in the quality would undoubtedly lead to greater consumption of parboiled rice.

Although the engineering and hygienic aspects of parboiling have received considerable attention in recent years, few comprehensive studies have been made on factors affecting the quality of parboiled milled rice. Earlier studies made on rice quality were limited mainly to specific processing conditions.

The objectives of the work described in this bulletin were to determine under controlled laboratory conditions the effects of variations of soaking temperature, soaking time, and steam temperature in the parboiling process on eight selected qualities and characteristics of milled rice.

LITERATURE REVIEW

Milling and Processing

Jones and Taylor in 1935 (*26*) investigated the effect of parboiling on long- and medium-grain commercial rice varieties grown in the United States. In this study the grains were soaked in water at room or controlled temperatures for the required length of time and steamed in a pressure cooker or in an autoclave with steam temperature at 122 ± 1°C. Samples soaked for 24 hours at room temperature and steamed for 15 or 25 minutes were reported to show increased yield of head rice for all varieties, with one exception. The increase in head rice, as a result of parboiling, was essentially the same regardless of the soaking period, the temperature of water in which the rice was soaked, or the time of steaming. It was also noted that the color and texture of the parboiled milled rice was affected by the soaking and steaming conditions.

Studies on 12 different parboiling and related treatments and their effects on the quality of long-, medium-, and short-grain varieties were made by Jones, Taylor, and Zeleny (*27*). It was shown that soaking rough rice for 24 hours resulted in excessive breakage in all varieties studied. Soaking in water at 96°C for 2.5 minutes with steaming at 15 lb. pressure for 15 minutes increased breakage in the short-grain variety, had no effect on the medium-grain, and improved the milling quality on the long-grain variety. All other treatments except one materially increased the yield of head rice. The average increase in head rice yield of the three varieties was 8% for the siddha, sela, and josh treatments and 28% for the other parboiling treatments.

The rice "conversion" process (*12*) and its influence on yield was studied by Kik (*35*). Rough rice was placed into large vessels under a vacuum of 25 inches of mercury for 10 minutes. Hot water (73°–85°C) under 80–100 lb. pressure was then introduced. The rice was soaked under this condition, with recirculation of the water, for periods ranging from 120 to 165 minutes. The water used in soaking was drained off and the soaked paddy was transferred into a large, steam-jacketed vessel, which was then partially evacuated. Dry steam was introduced for a short time. A vacuum of 28 to 29 inches of mercury was applied. The result showed that the average proportion of broken kernels of converted rice was 3.5% compared with 19.5% for the unconverted sample.

The breakage of rice during shelling was noted by Kik (*31*) during his investigations on thiamin loss during parboiling. Prolonged boiling reduced breakage from an average of 37.8% to 27.6% and subsequent steaming further reduced breakage to 6.8%.

Subrahmanyan et al. (*52*) suggested new procedures for production of improved quality parboiled rice in India. The procedure developed was similar to that adopted for the converted rice (*12, 35*). Instead of adding steam into a large amount of cold water, as in the conventional method (*53*), the water in the tank was heated to an initial temperature of 60° – 65°C by live steam and the paddy added after steaming. In the pilot study, it was reported that absorption of water for complete gelatinization of starch was decreased by three hours. When the soaked paddy was steamed for 5 – 10 minutes, the yield of head rice was the same by weight in comparison with commercial methods. It was also noted that the yields of head rice and breakage during milling of partially parboiled rice were intermediate between fully parboiled and raw samples.

Mecham et al. (*41*) studied yields of parboiled rice in relation to water uptake under different soaking conditions. These investigations showed differences among lots of rice in both water uptake and temperature requirements for adequate soaking. The total water requirements and the time needed for distribution of water within the kernel (to provide for gelatinization of the starch granules in the center of the kernel upon cooking) also differed. Soaking at temperatures much above 150°F caused some of the kernels to burst and the mass of the rice to become sticky and slimy because of starch gelatinization. In properly soaked rice, gelatinization of starch within the kernels was obtained by cooking for 5 minutes at 20 lb. pressure or 8 minutes at 10 lb. Results were also satisfactory with cooking at 30 or 40 lb. pressure for shorter times, but at these high pressures overcooking quickly caused the product to darken. Improper soaking and inadequate cooking resulted in incomplete gelatinization with a high proportion of broken kernels in the dried and milled product.

A comprehensive study of processing factors and their relationship to milling yields was made by Bhattacharya et al. (*6*). They reported that absorption of water by the paddy increased with temperature but was considerably below the gelatinization point. Beyond the gelatinization point the grain absorbed water rapidly, preferentially on surface layers, leading to early bursting and leaching. Milling quality depended on the severity of heat treatment during parboiling and the conditions of drying. The more severe the heat treatment, the better the treated rice was able to withstand the adverse drying. Other results reported by Bhattacharya were that insufficient soaking led to increased breakage; simple soaking of paddy at or above 70°C improved milling quality; and the rate of hydration of the paddy, as well as improvement in its milling yields by parboiling, showed varietal differences.

The results of the investigations performed at the International Rice Research Institute, Philippines, on the effect of parboiling on seven varieties of rice differing in amylose content have shown that the values of the breaking and crushing hardness, as measured with a Kuya-type tester, were higher for all parboiled samples than for the raw samples. The head rice yield at 4% bran was 99% of the total milled rice in all parboiled samples, whereas the average for the raw rice samples was 75.3%.

Craufurd (*15*) investigated effects of post-harvest sun drying, shade drying, and two artificial drying methods on yields of rice. He reported that these drying treatments did not affect milling yields. Sun drying, followed by parboiling and shade drying to 12% moisture content, gave 70% whole grain. Shade drying, followed by parboiling and shade drying to 12% moisture content, gave 60% whole grain. In a later study, Craufurd (*15*) noted that, in drying of rice, if the intensity of shade could be adjusted to keep the paddy temperature at 36 ± 1°C, serious loss of milling quality could be avoided.

Investigations by Bhattacharya (*9*) showed that parboiled paddy dried in the shade had excellent quality, but rapid drying with hot air (40°–80°C) or in the sun give high breakage. Two-staged drying with a tempering prior to attainment of the critical moisture content would also preserve milling quality. Tempering at higher moisture content, however, was less efficient, and multiple tempering gave no additional benefit. Drying in two phases, with a tempering in moisture range of 15% to 19% followed by hot conditioning after the final drying, was reported to give milling breakage not exceeding 2%.

Further investigation by Bhattacharya (*11*) showed that single-stage drying had no damaging effect on milling yields of rice until the moisture content had dropped below 16%. Hot storage for 3 hours following drying prevented or reduced, but did not eliminate, breakage. Two-staged drying, with tempering at 16% moisture, resulted in breakage no higher than that of the sun-dried control. Tempering at a slightly lower moisture content appeared to give slightly higher breakage.

The relationship between moisture content after drying, time of storage (tempering time), total rice yield, and percentage of brokens was reported by Sluyters (*51*). Neither the moisture content nor the storage time appeared to have an effect on the milled rice yield. At low moisture content the percentage of broken grain, expressed as the percentage of total rice yield, rose rapidly within three hours after drying. The lowest percentage of brokens occurred at 16% to 17% moisture.

Bhattacharya (*10*) investigated the relationship of kernel defects to breakage. He reported that cracks (whether inherent or freshly induced), immaturity, and chalkiness in the kernels were completely eliminated by parboiling. He concluded that parboiling was an excellent tool for salvaging paddy that contained a high proportion of immature kernels, or paddies that had been improperly harvested, improperly dried, or inadvertently damaged.

Jayanarayanan (*24*) investigated the effects of various processing conditions on the browning of parboiled rice. The investigation was concerned with the influence of steeping time and temperature, steaming pressure and time, pH of the steeping water, alpha-amylase activity, drying temperature, and sodium bisulfite concentration in the steeping water, on the discoloration or browning of parboiled rice. In the studies seven sets of parboiling experiments were designed to study each objective. From the results, he concluded that the steeping and steaming temperatures as well as the steeping and steaming times influenced browning or discoloration of parboiled rice. The pH of the steeping water was equally very important. It was found that raw rice amylases favored browning by the formation of reducing sugars during steeping.

Several highly mechanized parboiling processes were developed and introduced into the rice processing industry over the last two decades. The Avorio, Conversion, Yon-Malek, Fernandes, and Cristallo processes have been described in detail (*1, 12, 27, 44*). A review of these processes by Matz (*38*) indicated that yields of 66 to 71 pounds of total milled rice and 58 to 68 pounds of whole grain could be obtained from 100 pounds of starting rough rice.

Nutrients in Rice

Data on the composition of rice and rice products were published by Watt and Merrill (*56*) and McCall et al. (*39*). A comprehensive tabulation of compositional data for rice was compiled by Juliano (29) together with an extensive bibliography of articles from which the data were taken.

Summaries of the vitamin content of rices were compiled by F.A.O. (*17*), McCall and co-workers (*39*), Juliano (*29*), Kik (*34*), and Kik and Williams (*33*).

The protein content and the amino acid profiles of rice and rice products were reviewed by Houston and Kohler (*21*).

Studies by Juliano and co-workers (*28*) revealed that the protein content of rough, brown, and milled rice varied significantly among varieties. The Asian varieties were generally of lower protein content than those varieties planted in the United States, with one exception in the first crop and one exception in the second crop. They also observed a difference of about 4% in protein content of the same variety of rice planted at different seasons.

McCall et al. (*40*) investigated the influence of variety and environment on the physical and chemical composition of different rice varieties. They reported that both variety and environment had a highly significant influence on yields of milling and anatomical fractions of rough rice and the composition of true bran. Variety had a highly significant influence on the nitrogen content of white rice and the ash content of hulls. Environment had a highly significant influence on the ash content of hulls, and on the lipid, nitrogen, ash, and starch contents of the white rice.

Borasio and Gariboldi (*12*) made a comparative study of the protein contents of the Avorio and Cristallo processed rice. They reported a protein content of 6.30% for Avorio rice, 6.95% for Cristallo rice, and 6.10% for normal milled rice. It was pointed out that the improved chemical composition of milled parboiled rice was due to the decrease in removal of material during milling because of the hardness of the kernels.

Cagampang et al. (*13*) reported results of solubility studies on protein fractions of milled rice, bran, and rice polish of high and low protein samples. They showed that glutelin was the predominant fraction in the whole grain, milled product, and rice polish. Albumin and globulin were the major proteins of the bran and they were concentrated in the bran and polish, whereas prolamine was rather evenly distributed in all three fractions. They also pointed out that differences in the total protein content of the whole grain were due mainly to differences in glutelin content.

The influence of parboiling on the protein fractions was studied at the International Rice Research Institute (*21*). It was reported that parboiling had no effect on protein content but drastically reduced the extractability of protein, in all samples studied, by an average of 45%. The globulin fraction, however, showed the largest reduction, namely 65%.

Tamura and co-workers (*55*) reported the amino acid composition of the four main protein fractions of milled rice. They found high concentrations of lysine in albumin, of cystine in globulin, and of leucine and proline in prolamine.

Juliano and co-workers (*28*) found significant negative correlations between crude protein content and percentages of lysine, methionine, and threonine in a series of 16 rices. Positive correlations were found for tyrosine, arginine, and leucine.

Hunter, Ferrel, and Houston (*22*) reported results of a study on free amino acids in fresh and aged parboiled rice. Those in greatest initial concentration were alanine, aspartic acid, and glutamic acid. Those in intermediate concentration were arginine, asparagine, glycine, leucine, lysine, proline, serine, valine, and one unidentified ninhydrin-reacting compound. Those in the lowest concentration were cystine, histidine, methionine, phenylalanine, threonine, trytophan, and tyrosine. A significant loss of amino acids during accelerated storage, as indicated by the intensity of the amino acid spots, was also reported.

Aykroyd, Krishman, and Sundararajan (*3*) pointed out that machine-milled rice from raw rough rice contained 1.0 μg/g of vitamin B_1. Machine-milled rice from parboiled rice contained 2.20 μg/g. Similarly, milled rice from raw rice had 16 μg/g nicotinic acid, while milled rice from parboiled rice had 38 μg/g.

According to Kik et al. (*31*) rough rice or paddy had 3.0 μg/g of B_1 and polished rice 0.6 μg/g, while rice bran had 21–31 μg/g. Later, Kik (*32*) reported that rice from the Conversion and Malekised processes showed greater retention of vitamin than untreated rice.

The distribution of thiamin in rice was discussed by Simpson (*50*). He confirmed that thiamin was largely centered in the scutellum but riboflavin was more uniformly distributed throughout the embryo.

Investigations on vitamin losses during parboiling and mechanical drying were made by Mitra and Chandhuri (*43*). Using Rupsal, Patnai, and Sitosal varieties grown in West Bengal, they reported that loss of vitamin was negligible. About 17–20% of thiamin was lost along with the bran on hulling.

Bhattacharaya and Rao (*8*) studied the effect of parboiling conditions on thiamin content of rice. They found that parboiling destroyed part of the total thiamin content of paddy. Soaking *per se* did not lead to loss, but much thiamin was leached out when the rough rice split during soaking. They reported that soaking at high pH also may reduce thiamin. The thiamin was protected against loss during milling by high temperature soaking or by soaking and steaming, but not by soaking alone at lower temperatures.

Rice Quality

Parthasarathi and Nath (*45*) studied water absorption by rice cooked for 30 minutes in excess water at different temperatures. The amount of water absorbed by the rice was taken as the criterion for the degree of cooking. Differences in water absorbed by different rice varieties were noted.

Rao et al. (*46*) recorded water absorption as swelling number, or the weight of water absorbed by rice when cooked in excess water at 98°C under standard conditions. They found a close association between the amylose content of rice and its swelling number. They reported that rice having a high swelling number was well liked by consumers because such rice was soft when cooked.

Halick and Kelly (*19*) reported water uptake at temperatures ranging from 72° to 82°C as important indicators of rice quality. Water uptake by whole rice at temperatures ranging from 72° to 82°C were closely related to gelatinization of starch in the rice kernel. They concluded that short- and medium-grain varieties with low gelatinization temperatures absorbed more water than did the long-grain varieties, with certain exceptions.

The water absorption value and the content of dissolved materials in the cooking water were used by Hogan and Plank (*20*) to evaluate 10 different varieties of milled rice. They reported that water uptake was greatest with short-grain, least with the long-grain, and intermediate with the medium-grain. Short-grain varieties gave the greatest amount of dissolved solids in the treating water while the long-grain varieties gave the least.

Batcher and co-workers (*4*) developed methods for measuring the water uptake, volume, residual starch, and total residual solids in cooking water. The tests indicated that the long-grain rice absorbed more water and when cooked had greater volume than the medium- or short-grain rices. There was less solid material in the residual cooking liquid obtained from long-grain rice than in the liquids associated with the other varieties tested. A significant correlation was observed between the water uptake ratio and cohesive score. Water uptake ratio and flavor were also highly significantly correlated.

In a later study Batcher et al. (*5*) evaluated 26 varieties of milled white rice. The long-grain varieties tended to absorb more water than the other grain types, although there were exceptions. They concluded that grain type appeared to be associated with water absorption but some overlapping occurred. Residual cooking liquids from most of the long-grain varieties had less total solids and starch than the liquids from short- and medium-grain varieties. However, Century Patna and Toro had greater amounts of total solids in residual cooking liquids than other long-grain varieties.

The use of a starch-iodine blue test as a quality indicator of white milled rice was investigated by Halick and co-workers (*18*). The intensity of the blue color produced by addition of the iodine solution was indicative of the amylose leached or diffused from the ground rice under the condition of the test. They obtained low readings with varieties known to be of superior quality, while varieties known to be of poor quality gave high readings. A good correlation was reported between results of this method and those of actual cooking tests.

Investigation by Warth and Darabsett (*57*) showed that different varieties of rice disintegrated in alkali solution in a consistent order. Kernel disintegration and gelatinization were complete in some varieties in 24 hours, but in others were incomplete after that time, as indicated by a diffused white area adjacent to the kernels.

Jones (*25*) reported an association between kernel disintegration in a 2.8% potassium hydroxide solution and the cooking quality of rice. He observed that the temperature during the time of disintegration affected the degree of degradation, but not all varieties responded similarly.

Little et al. (*37*) used a seven-point numerical scale for spreading and clearing of white milled rice kernels that had been in a 1.7% potassium hydroxide solution for 23 hours. They reported that slight to moderate spreading and clearing was characteristic of most of the long-grain varieties and a more severe degradation was associated with medium- and short-grain varieties. The values for spreading and for clearing were negatively correlated with the panel score for cohesiveness.

Roberts et al. (*48*) used expanded volume, color, and soluble starch as quality indicators of parboiled rice. They reported that severity of heat treatment during the parboiling process increased the degree of expansion of the dry milled rice, darkened the color, and increased the soluble starch content of the product. Steaming temperatures exhibited the greatest influence on all these factors.

Kurien and co-workers (*36*) used swelling rates and swelling ratios as measurements for the swelling quality of rice. Raw rice was cooked for 15–20 minutes, while parboiled rice was cooked for 20–40 minutes to attain a soft consistency. At that stage of cooking, they observed that the average length, breadth, volume, and weight of cooked parboiled grains were generally greater than the corresponding values for cooked raw rice.

Bhattacharya and Rao (*7*) studied the effect of processing conditions on cooking quality of parboiled rice. Water uptake, iodine blue value of the gruel, and solids in gruel were used as measurements of cooking characteristics. They reported that soaking affected the quality only above 60°C. The greater the severity of heat treatment during soaking and steaming, the lower the water uptake and the darker the color of the rice. Soaking at 70°C, and above, had a greater effect on the color of the rice, whereas steaming affected the cooking to a greater extent.

MATERIALS AND METHODS

Based upon practical considerations of the effects of temperature and length of time of soaking rice in heated water with subsequent steaming, three levels of water temperature during soaking—50°, 60°, and 70°C—together with five periods of elapsed time during soaking—3, 6, 9, 12, and 15 hours—were chosen for study in these experiments. These levels of temperature and periods of time yielded 15 different groups of soaked rice.

For each of these 15 groups, control samples consisting of only shelled and milled (or raw) rice were included in the study; also included were 15 samples representing the various soaked but unsteamed groups.

Three steam temperatures—100°, 110°, and 120°C—were selected for each of the 15 groups. These yielded 45 different kinds of parboiled rice, that is, rice that had been both soaked and steamed. Thus, 75 samples of rice consisting of 15 controls, 15 soaked but not steamed, and 45 samples of soaked and steamed products were obtained. Since all the operations were performed in replicate, a total of 150 batches of rice were prepared and used in studying the effects of various levels of water temperature during soaking, elapsed time during soaking, and steam temperature on eight characteristics of rice, namely, total yield of milled rice, percent of head rice in the milled product, color of milled rice, protein content of brown rice, protein content of milled rice, water uptake ratio of milled rice, volume of cooked milled rice, and residual solids in cooking water.

Each of the eight variables measured was evaluated according to a 5 × 3 × 5 factorial arrangement of treatments (5 kinds of group treatments which included 3 levels of steam temperature × 3 levels of temperature of the water in which the rough rice samples were soaked × 5 levels of elapsed time during soaking) in a randomized block design with 2 replicates. The data for each variable were subjected to a standard analysis of variance for a mixed model in which grouping of treatments was regarded as a fixed effect, and temperature of water during soaking and elapsed time during soaking were regarded as random effects.

Rice Samples

The rice used in this study was Dawn, a long-grain variety, planted at the Rice Experiment Station, Crowley, Louisiana, where in September 1970 it was harvested, cleaned, and dried to a moisture content of 12% in an L.S.U. type dryer. After being transported to the Baton Rouge campus, the rice was further cleaned in a clipper seed cleaning machine to remove the impurities and foreign materials that had escaped the primary cleaning operations. The cleaned rice was divided into two lots, Replicate I and Replicate II, each weighing about 40 kilograms. Each replicate lot was passed separately through a Boerner Sample Divider, one kilogram at a time. Seventy-five representative samples, each weighing 300 grams, were prepared from each of the two replicate lots, thus yielding a total of 150 samples, each of which was stored individually in a polyethylene bag. The two 75-sample replicate lots were kept separately in metal containers and were stored at room temperature for one month or less before being used.

Processing of Rough Rice

Each 300-gram sample, except the 15 raw controls, was placed in a one-liter beaker to which was added 750 milliliters of distilled water, pH 6.9. The beaker was placed in a constant-temperature water bath and the contents were stirred manually with a glass stirrer. After soaking at the appropriate temperature—50°, 60°, or 70°C—for the proper length of time—3, 6, 9, 12, or 15 hours—the sample was transferred onto an 8" × 8" metal screen and drained for 5 minutes to remove excess water. The metal screen and sample to be steamed were placed in an autoclave and subjected to the appropriate steam temperature—100°, 110°, or 120°C—for 10 minutes. Each steamed sample was spread on aluminum foil, 24" X 24", and allowed to dry at room temperature (about 25°C) for 48 hours, or less, until the moisture content was 12% as determined with a Motomco electric moisture tester. The dried samples were stored in polyethylene bags at room temperature until they were milled.

Milling and Grading

Exactly 150 grams of rice from each sample was taken and shelled in a McGill sheller to remove the hulls. The machine was set according to U.S.D.A. specifications for milling Southern long-grain rice (*47*). The samples of brown rice thus obtained were kept in polyethylene bags that were stored at 40°F until they were removed for polishing.

The polishing operation, or removal of the bran from the brown rice, was done in a Satake Testing Pearler, Model OM–2B. The milled rice thus obtained was weighed and the percent recovery or milling yield was computed, based on the original weight of the rough rice sample. The samples of milled rice were individually placed in polyethylene bags that were kept in metal containers stored at 40°F.

Brown rice samples for use in the Kjeldahl nitrogen determinations were obtained in each instance by shelling the portion of the 300-gram sample of rough rice that remained after removal of the 150-gram sample for processing. The 150 samples of brown rice thus obtained were stored at 40°F.

The milled rice samples were assayed for head rice by use of a Grain Sizing Device (*47*). Final separation of the broken kernels from the head rice was made manually, grain by grain. The head rice obtained from each sample of milled rice was weighed and the percentage of head rice in the milled rice, which is an index of quality, was computed. The samples of head rice were transferred into polyethylene bags and stored at 40°F prior to color, protein, and cooking tests.

Color Measurements

The color of the milled rice was measured by means of a Gardner Digital Color and Color Difference Meter, Model X–10, with L, a, and b scales. Only whole kernels were used in the determination. A 20-gram sample was put into a glass cuvette and placed on the aperture plate. The sample was read against a reference White Reflectance Standard No. 1093 (with L value 91.6, a_L value 1.3, and b_L value 0.1), supplied by the manufacturer. Each sample was read a number of times by pouring the samples and refilling at least three times. The average L, a_L, and b_L readings were recorded. The total color difference, E, between the standard and each of the specimens was computed by using the formula $E = \sqrt{\Delta_L^2 + \Delta a^2 + \Delta b^2}$ where Δ_L, Δa, and Δb are the respective differences between the sample and the standard.

Protein Analysis

Kjeldahl protein of brown and milled rice was determined according to the approved method of the A.O.A.C. (*2*).

Moisture Determination

Moisture content of milled and brown rice was determined by A.O.A.C. (*2*) approved method.

Cooking Tests

Cooking tests were conducted according to the method of Batcher et al. (*4*), Bhattacharya and Rao (*7*), and Roberts et al. (*48*) with certain modifications. Three basic characteristics were determined, namely, water uptake ratio, volume of cooked rice, and total solids in the residual cooking liquid (TSRCL). Numerical values for these three attributes were obtained in sequence, using one weighed sample of milled rice. A total of 150 5-gram samples of milled rice were individually cooked in wide glass tubes containing 50 milliliters of distilled water. The glass tubes were immersed for 20 minutes in a beaker of boiling water that was heated on an electric hot plate. Each sample of cooked rice was drained on a sieve, and after the excess moisture had been quickly blotted with filter paper, the cooked rice was weighed to obtain the water uptake ratio, that is, the number of grams of water absorbed per gram of rice. Immediately after the weighing operation, the volume of the cooked rice was determined by the water displacement method. Solids in the residual cooking liquid were determined by evaporating the cooking water to dryness in a tared 25-ml glass beaker in an oven at 100°C for 24 hours. The weight of the residual solids was divided by the weight of the raw sample and the results were recorded as milligrams of TSRCL per gram of rice.

RESULTS AND DISCUSSION

Results of the analysis of variance for the eight sets of data are presented in Table 1. The four sources of variation in the experiments affected the eight characteristics of milled rice as follows:

(1) Small, but significant, differences between the two replicate experiments existed for: total yield of milled rice, head rice yield, water uptake ratio, volume of cooked rice, and residual solids in cooking water. Unaffected by replication were: color of milled rice and protein content of brown and milled rice.

(2) Significantly associated with elevating the temperature of the soaking water were: increased total yield of milled rice, darkened color, and reduced values for water uptake ratio, volume of cooked rice, and residual solids in cooking water. Head rice yield and protein content of brown and milled rice were not affected by soaking temperatures.

(3) Significantly associated with increased lengths of soaking time were: increased yields of head rice, darkened color, and reduced values for water uptake ratio and volume of cooked rice. Not affected by soaking time were: total yield of milled rice, protein content of brown or milled rice, and residual solids in cooking water.

(4) The soaking and steaming operations did not affect the protein content of brown or milled rice. The steaming operation was significantly associated with: increased total yield of milled rice, increased yield of head rice, darkened color, and reduced values for water uptake ratio, volume of cooked rice, and residual solids in cooking water.

Total Yields of Milled Rice

The mean percentages for total yields of milled rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, B × C; and the trivariate interaction, A × B × C, along with the overall mean are given in Table 2.

TABLE 1.—ANALYSIS OF VARIANCE FOR EIGHT VARIABLES OF PARBOILED *DAWN* RICE

SOURCE OF VARIATION	d.f.	MEAN SQUARES: PERCENT YIELDS: Milled from Rough	PERCENT YIELDS: Head Rice in Milled	COLOR	PERCENT PROTEIN: In Brown Rice	PERCENT PROTEIN: In Milled Rice	COOKING QUALITIES: Water Uptake Ratio	COOKING QUALITIES: Volume Cooked Milled Rice	COOKING QUALITIES: Residual Solids in Cooking Water
Total	149								
R—Replicate	1	6.76**	91.49**	0.003	0.0129	0.0091	0.082*	1.57*	1.36**
A—Grouping (fixed effect)	4	307.70**	4046.15**	2048.89**	0.0189	0.0346	3.594**	101.93**	13.14**
B—Soak. Temp. (random effect)	2	2.64*	214.27	203.20**	0.0998	0.0228	0.416**	6.95**	2.32*
C—Soak. Time (random effect)	4	1.25	445.90*	65.77**	0.0377	0.0906	0.101**	2.18**	0.36
AB—Grouping × Soak. Temp.	8	0.35	62.66**	15.68**	0.0461	0.0969*	0.191**	3.06**	0.48*
AC—Grouping × Soak. Time	16	0.46	56.95**	6.48**	0.0713	0.0479	0.023	0.90**	0.25
BC—Soak. Temp. × Soak. Time	8	1.53	71.34**	1.69**	0.0647	0.0476	0.016	0.12	0.40**
ABC—Grouping × Soak. Temp. × Soak. Time	32	1.28*	16.87*	1.75**	0.0962*	0.0238	0.009	0.29	0.17*
Error	74	0.77	9.45	0.29	0.0599	0.0431	0.017	0.34	0.09

**$p<0.01$
*$p<0.05$

TABLE 2.—MEAN PERCENTAGES FOR TOTAL YIELDS OF MILLED RICE

TRIVARIATE INTERACTION, A×B×C							BIVARIATE B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	65.33	62.90	70.27	71.52	70.72	68.15
	6	65.95	64.50	72.32	71.50	70.44	68.94
	9	65.40	65.94	71.54	71.30	71.42	69.12
	12	64.50	67.35	71.08	71.48	71.82	69.25
	15	65.75	67.12	72.03	71.92	71.44	69.65
60°	3	65.33	66.62	70.93	71.10	71.14	69.02
	6	66.02	65.64	71.33	71.08	71.28	69.07
	9	65.85	65.54	71.39	71.21	71.54	69.11
	12	66.21	65.23	71.64	71.77	71.37	69.24
	15	65.88	64.78	71.66	70.76	71.92	69.00
70°	3	66.10	66.60	71.25	71.23	71.80	69.40
	6	66.00	67.55	72.98	71.56	71.96	70.01
	9	66.23	64.52	71.16	71.76	72.02	69.14
	12	66.10	65.32	71.84	71.96	72.04	69.45
	15	65.02	65.06	71.89	72.22	72.04	69.25
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	65.59	65.37	70.82	71.29	71.22	68.86
	6	65.99	65.90	72.21	71.38	71.23	69.34
	9	65.83	65.33	71.36	71.42	71.66	69.12
	12	65.60	65.96	71.52	71.74	71.74	69.31
	15	65.55	65.66	71.86	71.64	71.80	69.30
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	65.39	65.56	71.45	71.54	71.17	69.02
	60°	65.86	65.56	71.39	71.18	71.45	69.09
	70°	65.89	65.81	71.82	71.75	71.97	69.45
GROUP MEANS A		65.71	65.64	71.55	71.49	71.53	OVERALL MEAN 69.19

For Replicate I the mean value was 68.97%, whereas for Replicate II it was 69.40%. The difference between the means of the two replicates, 0.43%, although small, was highly significant ($p < 0.01$).

The processing treatments to which the five groups of rough rice samples were subjected very significantly ($p < 0.01$) affected the total yield of milled rice. The mean total yields associated with the five treatments were: raw (untreated), 65.71%; soaked but not steamed, 65.64%; and for those samples steamed at 100°, 110°, and 120°C, the yields were 71.55, 71.49, and 71.53%, respectively.

The temperature of the water during soaking significantly affected ($p < 0.05$) the total yield of milled rice obtained from the treated rough rice. The highest temperature of the water during soaking was associated with the highest yield. For rice soaked in water at 50°C the mean yield of milled rice was 69.02%; at 60°C it was 69.09%; and at 70°C it was 69.45%.

Increasing the length of time that the rough rice was soaked in hot water prior to milling had no significant effect ($p > 0.05$) on the mean total yields. The five periods of time during which the rough rice was soaked, namely, 3, 6, 9, 12, and 15 hours, were associated respectively with the following total yields of milled rice: 68.86, 69.34, 69.12, 69.31, and 69.30%.

All three bivariate interactions, A × B, A× C, and B × C, for total yields of milled rice were not significant ($p > 0.05$). This indicates that, with respect to mean total yields of milled rice, relationships between groups of samples × water temperature during soaking, between groups of samples × elapsed time during soaking, and between water temperature during soaking × elapsed time during soaking were consistent for all batches of treated rice.

In the A × B interaction, groups of samples × water temperature during soaking, the lowest yields of milled rice were associated with the lowest soaking temperature, 50°C, and the absence of steam treatment, whereas the best yields were associated with the highest soaking temperature, 70°C, and treatment with steam.

In the A × C interaction, groups of samples × elapsed time during soaking, the mean total yields for the two unsteamed groups ranged from 65.33% to 65.99%; among the three steamed groups the total yields ranged from 70.82% to 72.21%. These values indicate that treating the soaked rice with steam, whether at 100°, 110°, or 120°C, increased the yield of milled rice about 6%, based on the weights of the rough rice samples; furthermore, these relationships were not affected by the length of time the samples were soaked prior to being steamed.

In the B × C interaction, water temperature during soaking × elapsed time during soaking, the mean total yields of milled rice associated with a soaking temperature of 50°C increased slightly from 68.15% to 69.65% as the soaking time increased from 3 hours to 15 hours; a similar but less definite trend was apparent when the rough rice was soaked in water at 60° or 70°C.

In the trivariate interaction, A × B × C, the mean yields among the 30 samples of the two unsteamed groups ranged from 62.90% to 67.55%. These values were associated with samples of rough rice that had been soaked at 50° and 70°C for 3 and 6 hours, respectively. The mean percentages for the other 45 samples in the three steamed groups ranged from 70.27% to 72.98%; the smaller value was associated with samples of rough rice that had been soaked in water at 50°C for 3 hours and then steamed at 100°C, whereas the larger value, also from samples steamed at 100°C, was associated with 70°C as the temperature of the water in which it was soaked, and 6 hours as the period of soaking time. The trivariate interaction for total yields of milled rice was significant ($p < 0.05$). This indicates that, with respect to the mean percentages of total milled rice obtained from the rough rice samples, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were not consistently maintained for all batches of rice.

Yields of Head Rice

The mean percentages for yields of head rice, based on the weights of the corresponding samples of milled rice, for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, and B × C; and the trivariate interaction, A × B × C, together with the overall mean are given in Table 3.

The mean yields of head rice for Replicates I and II were 80.91 and 82.48%, respectively. The difference between the two means, 1.57%, was highly significant ($p < 0.01$). Replicate II not only gave a significantly greater mean total yield of milled rice, as was noted in the preceding section, but also contained a significactly larger proportion of head rice in the milled product than did Replicate I. The significant difference in yields suggests that the degree to which the samples in Replicate II were milled was slightly less than that to which those in Replicate I were milled.

The processing treatments to which the five groups of rough rice were subjected very significantly affected ($p < 0.01$) the proportions of head rice in the milled product. The mean percentages of head rice associated with the five treatments were: raw, 75.18%; soaked but not steamed, 64.42%; and for those steamed at 100°, 110°, and 120°C, the yields were 87.14, 90.31, and 91.42%, respectively. These values indicate that the effect of soaking rough rice in hot water was to reduce the proportion of head rice in the milled product by nearly 11%. The effect of treating the soaked rice with steam was to increase substantially the proportion of head rice in the milled product due to the gelatinization and hardening of the kernels during the steaming process. The highest steaming temperature, 120°C, was associated with the highest yield of head rice.

Increasing the temperature of the water in which the rough rice was soaked from 50°C, or from 60°C, to 70°C tended to increase the proportion of head rice in the milled product but this effect was not statistically significant ($p > 0.05$). Mean yields of 80.31, 80.70, and 84.08% for head rice were associated respectively with soaking temperatures of 50°, 60°, and 70°C.

Increasing the length of time from 3 hours to 9 hours that the rough rice samples were soaked in hot water significantly increased ($p < 0.05$) the proportion of head rice in the milled product from 75.22% to 84.35%, but the mean percentages of head rice, 83.86% and 84.00%,

TABLE 3.—MEAN PERCENTAGES FOR HEAD RICE IN MILLED RICE

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	75.41	62.08	63.44	70.03	75.55	69.30
	6	74.70	63.22	84.88	88.40	85.70	79.38
	9	74.20	74.97	92.29	92.69	92.78	85.38
	12	74.36	64.17	90.70	92.27	92.94	82.89
	15	75.10	70.25	92.77	92.76	92.14	84.60
60°	3	75.28	58.68	73.10	82.69	86.79	75.31
	6	75.30	60.14	81.95	88.04	91.14	79.32
	9	75.55	60.92	87.15	91.02	93.74	81.68
	12	76.10	64.82	90.80	93.24	93.97	83.78
	15	75.12	62.87	91.57	93.26	94.26	83.42
70°	3	75.82	59.14	85.26	92.07	92.90	81.04
	6	74.70	69.84	91.12	92.91	93.69	84.45
	9	76.05	69.30	93.76	94.70	96.07	85.98
	12	74.88	66.62	94.28	94.33	94.49	84.92
	15	75.20	59.26	94.00	96.29	95.21	83.99
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	75.50	59.96	73.94	81.60	85.08	75.22
	6	74.90	64.40	85.98	89.78	90.18	81.05
	9	75.27	68.40	91.07	92.80	94.20	84.35
	12	75.11	65.20	91.93	93.28	93.80	83.86
	15	75.14	64.12	92.78	94.10	93.87	84.00
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	74.75	66.94	84.82	87.23	87.82	80.31
	60°	75.47	61.48	84.91	89.65	91.98	80.70
	70°	75.33	64.83	91.68	94.06	94.47	84.08
GROUP MEANS A		75.18	64.42	87.14	90.31	91.42	OVERALL MEAN 81.70

which were associated respectively with the 12-hour and 15-hour periods of soaking were slightly less than the value of 84.35% which was associated with the 9-hour soaking period.

All three bivariate interactions, A × B, A × C, and B × C, for mean percentages of head rice in milled rice were highly significant ($p < 0.01$).

In the A × B interaction, the group of untreated rough rice samples was associated with mean percentages of about 75% head rice in the milled product. The lowest yields of head rice, 61.48, 64.83, and 66.94%, were associated with unsteamed rice that had been soaked in water at 60°, 70°, and 50°C, respectively. Among the three steamed groups the mean proportions of head rice in the milled product ranged from

84.82% to 94.47%. These values indicate that treating the soaked rice with steam very substantially increased yields of head rice, with the greatest increases being associated with 70°C as the soaking temperature and 120°C as the steaming temperature. Statistically, the A × B interaction was highly significant ($p < 0.01$). This indicates that, with respect to mean percentages of head rice in the milled product, the relationship between groups of samples × water temperature during soaking was not consistently maintained for all batches of rice.

In the A × C interaction, as in the A × B interaction, the group of untreated rough rice samples was associated with mean percentages of about 75% head rice in the milled product. The mean values for the samples that had been soaked in hot water but not steamed ranged from 59.96%, which was associated with a 3-hour period of soaking, to 68.40%, which was associated with a 9-hour period of soaking. Among the three steamed groups the mean proportions of head rice in the milled product ranged from 73.94% to 94.20%; the smaller value was associated with a 3-hour period of soaking and steaming at 100°C, whereas the larger value was associated with a 9-hour period of soaking and steaming at 120°C. Statistically, the A × C interaction was highly significant ($p < 0.01$). This indicates that, with respect to mean percentages of head rice, the relationship between groups of samples × elapsed time during soaking was not consistently maintained for all batches of rice.

In the B × C interaction, increased proportions of head rice in the milled product were associated with increasing the soaking temperature from 50° to 60°C, or from 60° to 70°C, for soaking periods of 3, 6, or 9 hours. After the samples had been soaked for 9 hours, whether the water temperature during soaking was 50°, 60°, or 70°C, further extension of the soaking period to 12 or 15 hours usually had a slightly adverse effect on the yield of head rice. The smallest mean value, 69.30%, of head rice was associated with samples that had been soaked for 3 hours in water at 50°C; the largest mean value, 85.98%, was associated with samples that had been soaked for 9 hours in water at 70°C. Statistically, the B × C interaction was highly significant ($p < 0.01$). This indicates that, with respect to the mean percentages for yields of head rice, the relationship between water temperature during soaking × elapsed time during soaking was not consistent for all batches of rice.

In the trivariate interaction, A × B × C, the 15 untreated rough rice samples were associated with head rice yields that ranged from 74.20% to 76.10%, with the overall mean for this group being 75.18%. The mean yields for the samples that had been soaked in hot water but not steamed ranged from 58.68%, which was associated with 3 hours of soaking in water at 60°C, to 74.97%, which was associated with 9 hours of soaking at 50°C. Values between these two extremes fluctuated in an erratic manner with respect to lengths of soaking periods and temperatures of soaking water. For the 45 steamed samples the mean percentages of head rice in the milled product ranged from 63.44% to 96.29%; the smaller value was associated with samples of rough rice that had been soaked in water at 50°C for 3 hours and then steamed at 100°C, whereas the larger value was associated with 15 hours of soaking at 70°C followed by steam treatment at 110°C. In general, increasing the temperature of the steam treatment, or increasing the temperature of the water in which the samples were soaked, or increasing the elapsed time during which the samples were soaked, often tended to increase the mean percentages of head rice in the milled product. The trivariate interaction for mean percentages of head rice in milled rice was significant ($p < 0.05$). This indicates that, with respect to the mean percentages of head rice in the milled product, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were not consistently maintained for all batches of rice.

Color of Milled Rice

Each of the individual measurements, from which were computed the means for the total color difference values of milled rice, represented the magnitude of the total color differences between the standard and the sample. These values, however, give no indication of the character of the color difference because the relative quantity and direction of lightness, hue, and saturation differences are not indicated.

The means for total color difference values of milled rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, and B × C; and the trivariate interaction, A × B × C, along with the overall mean are given in Table 4.

The mean value for total color difference associated with Replicate I was 31.71, which is virtually identical with the value, 31.72, which was associated with Replicate II.

The different group treatments to which the rough rice samples were subjected greatly influenced ($p < 0.01$) the color of the milled product. The mean color values associated with the different groups were: raw, 21.37; soaked but not steamed, 25.05; and for those steamed at 100°, 110°, and 120°C, the values were 33.82, 37.35, and 40.97, respectively. Soaking the rice samples in hot water darkened the milled product. The effect of steaming was to darken the product further, with the mean color values increasing about 3.5 units for each 10-degree rise in steam temperature.

Increasing the temperature of the water in which the rough rice was soaked increased very significantly ($p < 0.01$) the mean values for total color difference. For water temperatures of 50°, 60°, and 70°C during soaking, the associated mean color values were 29.62, 31.87, and 33.65, respectively.

Increasing the length of time from 3 hours to 12 hours that the

TABLE 4.—MEAN COLOR VALUES OF MILLED RICE

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	21.00	20.27	27.98	31.88	36.70	27.57
	6	21.10	20.38	31.22	33.12	38.18	28.80
	9	21.44	20.50	31.50	33.36	38.46	29.05
	12	20.60	23.24	34.44	36.92	40.15	31.07
	15	21.43	23.42	34.71	37.32	41.28	31.63
60°	3	20.98	23.88	29.69	34.10	40.08	29.75
	6	21.54	22.74	32.68	38.45	40.90	31.26
	9	20.40	25.16	32.89	39.96	42.12	32.11
	12	21.44	27.00	35.92	39.10	42.10	33.11
	15	21.95	25.92	35.88	40.19	41.56	33.10
70°	3	21.60	25.56	31.14	37.33	41.20	31.36
	6	21.64	29.42	35.47	38.06	41.54	33.22
	9	21.82	29.78	37.05	39.10	42.60	34.07
	12	21.96	31.17	37.88	40.97	43.18	35.03
	15	21.71	27.28	38.88	40.34	44.50	34.54
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	21.19	23.24	29.60	34.44	39.33	29.56
	6	21.42	24.18	33.12	36.54	40.20	31.10
	9	21.22	25.15	33.81	37.48	41.06	31.74
	12	21.33	27.14	36.08	39.00	41.81	33.07
	15	21.70	25.54	36.49	39.28	42.44	33.09
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	21.11	21.56	31.97	34.52	38.95	29.62
	60°	21.26	24.94	33.42	38.36	41.35	31.87
	70°	21.75	28.64	36.08	39.16	42.60	33.65
GROUP MEANS A		21.37	25.05	33.82	37.35	40.97	OVERALL MEAN 31.71

rough rice samples were soaked in hot water very significantly ($p < 0.01$) darkened the color of the milled product. Extending the period of soaking from 12 to 15 hours had a negligible effect on the mean color value. For the different periods of soaking time, namely, 3, 6, 9, 12, and 15 hours, the associated mean total color difference values were 29.56, 31.10, 31.74, 33.07, and 33.09, respectively.

All three bivariate interactions, A $\times$ B, A $\times$ C, and B $\times$ C, for mean total color difference values of milled rice were highly significant ($p < 0.01$).

In the A $\times$ B interaction, the group of untreated rough rice samples had the least color; the values ranged from 21.11 to 21.75. The unsteamed rice samples that had been soaked in water at 50°, 60°, and 70°C were associated with mean color values of 21.56, 24.94, and 28.64, respectively. Among the three steamed groups the values ranged from 31.97 to 42.60. These values indicate that treatment of the soaked rice with steam appreciably darkened the color of the milled product, with the greatest darkening being associated with 70°C as the soaking temperature and 120°C as the steam temperature. Statistically, the A × B interaction was highly significant ($p < 0.01$). This indicates that, with respect to the mean values of total color difference, the relationship between groups of samples × water temperature during soaking was not consistently maintained for all batches of rice samples.

In the A × C interaction, the group of untreated rough rice samples gave the lowest color difference values, which ranged from 21.19 to 21.70. The mean values for the samples that had been soaked in hot water but not steamed ranged from 23.24, which was associated with 3 hours of soaking, to 27.14, which was associated with 12 hours of soaking. Associated with 15 hours of soaking was an intermediate value, 25.54. Among the three steamed groups, increasing either the length of the soaking period or the steam temperature increasingly darkened the milled product, the mean color values of which ranged from 29.60 to 42.44; the smaller value was associated with 3 hours of soaking and 100°C as the steam temperature, whereas the larger value was associated with 15 hours of soaking and 120°C as the steam temperature. Statistically, the A × C interaction was highly significant ($p < 0.01$). This indicates that, with respect to the mean values of total color difference, the relationship between groups of samples × elapsed time during soaking was not consistently maintained for all batches of rice samples.

In the B × C interaction, increasing the temperature of the water in which the rough rice was soaked, or increasing the length of time the rice was soaked, with two exceptions, darkened the color of the milled product, the mean values of which ranged from 27.57, which was associated with 3 hours of soaking at 50°C, to 35.03, which was associated with 12 hours of soaking at 70°C. Extending the period of soaking from 12 to 15 hours at 60°C had a negligible effect on color, and soaking at 70°C for 15 hours was associated with a mean color value of 34.54, which was 0.49 unit less than the value associated with 12 hours of soaking at 70°C. Statistically, the B × C interaction was highly significant ($p < 0.01$). This indicates that, with respect to the mean values of total color difference, the relationship between water temperature during soaking × elapsed time during soaking was not consistently maintained for all batches of rice samples.

In the trivariate interaction, A × B × C, the 15 untreated rough rice samples were associated with mean color values that ranged from 20.40 to 21.96, with the overall mean for the group being 21.37. The mean color values for the samples that had been soaked in hot water but not steamed ranged from 20.27 to 31.17; the smaller value was associated with 3 hours of soaking at 50°C, whereas the larger value was associated with 12 hours of soaking at 70°C. Values between these two extremes fluctuated, particularly with respect to lengths of soaking periods at 60°C. For the 45 steamed samples the mean values for the total color difference of the milled product ranged from 27.98 to 44.50; the smaller value was associated with samples of rough rice that had been soaked in water at 50°C for 3 hours and then steamed at 100°C, whereas the larger value was associated with 15 hours of soaking at 70°C followed by steam treatment at 120°C. In general, increasing the temperature of the steam treatment or increasing the temperature of the water in which the samples were soaked, or increasing the elapsed time during which the samples were soaked, tended to darken the milled product. Statistically, the trivariate interaction was highly significant ($p < 0.01$). This indicates that, with respect to the mean values of total color difference, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were not consistently maintained for all batches of rice samples.

Protein Content of Brown Rice

The mean percentages for protein content of brown rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, and B × C; and the trivariate interaction, A × B × C, together with the overall mean are given in Table 5.

The values for protein content among the 150 individual samples of brown rice ranged from 7.11% to 8.90%, with the overall mean being 8.23%. The mean percentage value for Replicate I was 8.24%; that for Replicate II was 8.22%. The difference between the two values was not significant ($p > 0.05$).

The processing treatments to which the five groups of rough rice samples were subjected did not significantly affect ($p > 0.05$) the protein content of brown rice. The mean values associated with the five treatments were: raw, 8.25%; soaked but not steamed, 8.19%; and for those steamed at 100°, 110°, and 120°C the values were 8.25, 8.21, and 8.22%, respectively.

The temperature of the water during soaking did not significantly affect ($p > 0.05$) the protein content of brown rice. Mean values of 8.18, 8.23, and 8.27% were associated with soaking temperatures of 50°, 60°, and 70°C, respectively.

Increasing the length of time that the rough rice samples were soaked in hot water had no significant effect ($p > 0.05$) on the protein content of brown rice. Associated with 3, 6, 9, 12, and 15 hours of soaking the rough rice samples in hot water were respectively the following mean values for protein in brown rice: 8.22, 8.21, 8.25, 8.27, and 8.18%.

These results indicate that neither replication, differences in group

TABLE 5.—MEAN PERCENTAGES OF PROTEIN IN BROWN RICE

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	8.20	8.04	8.14	8.02	8.15	8.11
	6	8.24	8.18	8.38	7.99	8.44	8.25
	9	8.18	8.14	8.16	8.44	8.18	8.22
	12	8.29	8.11	8.05	8.58	7.72	8.15
	15	8.21	8.22	8.42	7.80	8.21	8.17
60°	3	8.38	8.20	8.10	8.04	8.29	8.20
	6	8.37	8.15	8.27	7.70	8.12	8.12
	9	8.23	8.24	8.14	8.13	8.42	8.23
	12	8.44	8.69	7.98	8.50	8.38	8.40
	15	8.23	7.86	8.44	8.30	8.12	8.19
70°	3	8.40	8.34	8.40	8.27	8.28	8.34
	6	8.12	8.36	8.34	8.42	8.06	8.26
	9	8.24	8.20	8.38	8.48	8.16	8.29
	12	8.13	8.10	8.62	8.31	8.22	8.28
	15	8.14	8.08	7.90	8.17	8.64	8.19
BIVARIATE, A×C (Hours)							TIME MEANS C
	3	8.33	8.19	8.21	8.11	8.24	8.22
	6	8.24	8.23	8.33	8.04	8.21	8.21
	9	8.22	8.19	8.23	8.35	8.25	8.25
	12	8.29	8.30	8.22	8.46	8.10	8.27
	15	8.20	8.06	8.25	8.09	8.32	8.18
BIVARIATE, A×B (°C)							TEMP. MEANS B
	50°	8.23	8.14	8.23	8.17	8.14	8.18
	60°	8.33	8.23	8.19	8.15	8.27	8.23
	70°	8.20	8.22	8.33	8.33	8.27	8.27
GROUP MEANS A		8.25	8.19	8.25	8.21	8.22	OVERALL MEAN 8.23

treatment, water temperature during soaking, nor elapsed time during soaking, affected the protein content of brown rice.

All three bivariate interactions, A × B, A × C, and B × C, for mean percentages of protein in brown rice were not significant ($p > 0.05$). This indicates that, with respect to mean values for protein in brown rice, relationships between groups of samples × water temperature during soaking, between groups of samples × elapsed time during soaking, and between water temperature during soaking × elapsed time during soaking were consistent for all batches of rice.

The corresponding trivariate interaction, A × B × C, was significant ($p < 0.05$). Among the 75 mean percentages, the values ranged from

7.70% to 8.64%; the smaller value was associated with samples of rough rice that had been soaked in water at 60°C for 6 hours and then steamed at 110°C, whereas the larger value was associated with 15 hours of soaking at 70°C followed by steam treatment at 120°C. Between 7.70% and 8.64%, the values fluctuated in an erratic manner. Fluctuations were least in the group of raw samples, where the values ranged from 8.12% to 8.44%. The largest fluctuations, ranging from 7.72% to 8.64%, occurred in the group of samples that had been steamed at 120°C. This indicates that, with respect to mean percentages of protein in brown rice, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were not consistently maintained for all batches of rice.

Protein Content of Milled Rice

The mean percentages for protein content of milled rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, and B × C; and the trivariate interaction, A × B × C, along with the overall mean are given in Table 6.

The values for protein content among the 150 individual samples of milled rice ranged from 6.17% to 7.41%, with the overall mean being 7.12%, which is 1.11% less than 8.23%, the corresponding overall mean for protein content of brown rice. These values indicate that 13.5% of the protein in brown rice was removed in the milling operation.

The mean percentage of protein in milled rice for Replicate I was 7.11%; that for Replicate II was 7.13%. The difference between the two values was not significant ($p > 0.05$).

The processing treatments to which the five groups of rough rice samples were subjected had no significant effect ($p > 0.05$) on the protein content of milled rice. The mean values associated with the five treatments were: raw, 7.10%; soaked but not steamed, 7.09%; and for those steamed at 100°, 110°, and 120°C the values were 7.09, 7.16, and 7.15%, respectively.

The temperature of the water during soaking did not significantly affect ($p > 0.05$) the protein content of milled rice. Mean values of 7.13, 7.09, and 7.14% were associated with soaking temperatures of 50°, 60°, and 70°C, respectively.

Increasing the length of time that the rough rice samples were soaked in hot water had no significant effect ($p > 0.05$) on the protein content of milled rice. Associated with 3, 6, 9, 12, and 15 hours of soaking the rough rice samples in hot water were respectively the following mean values for protein in milled rice: 7.21, 7.11, 7.08, 7.10, and 7.08%.

These results indicate that neither replication, differences in group treatment, water temperature during soaking, nor elapsed time during soaking, affected the protein content of milled rice.

TABLE 6.—MEAN PERCENTAGES OF PROTEIN IN MILLED RICE

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	7.32	7.36	7.16	7.27	7.20	7.26
	6	6.94	7.08	7.04	7.11	7.12	7.06
	9	7.02	6.64	7.15	7.14	7.18	7.03
	12	6.72	6.91	7.29	7.31	7.24	7.09
	15	7.16	7.14	7.04	7.28	7.32	7.18
60°	3	7.19	7.26	7.07	7.06	7.22	7.16
	6	7.18	7.22	6.88	7.04	7.23	7.11
	9	7.07	7.16	7.16	7.13	7.06	7.12
	12	6.95	7.20	7.04	6.97	7.00	7.03
	15	7.16	7.18	7.08	6.72	7.12	7.05
70°	3	7.24	7.11	7.11	7.36	7.26	7.22
	6	7.16	7.19	7.04	7.24	7.24	7.18
	9	7.09	6.90	7.08	7.20	7.19	7.10
	12	7.08	7.14	7.24	7.30	7.14	7.18
	15	7.24	6.90	6.91	7.20	6.80	7.01
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	7.25	7.24	7.12	7.23	7.23	7.21
	6	7.10	7.16	6.99	7.13	7.20	7.11
	9	7.06	6.90	7.13	7.16	7.14	7.08
	12	6.92	7.08	7.19	7.19	7.12	7.10
	15	7.19	7.07	7.01	7.06	7.08	7.09
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	7.03	7.02	7.14	7.22	7.21	7.13
	60°	7.11	7.21	7.04	6.98	7.13	7.09
	70°	7.16	7.05	7.08	7.26	7.13	7.14
GROUP MEANS A		7.10	7.09	7.09	7.16	7.15	OVERALL MEAN 7.12

Of the three bivariate interactions, A × B, A × C, and B × C, only the A × B interaction, groups of samples × water temperature during soaking, was significant ($p < 0.05$). No two of the five groups of samples were alike with respect to the effects of increasing the water temperature during soaking on the protein content of milled rice. This indicates that, with respect to mean percentages of protein in milled rice, the relationship between groups of samples × water temperature during soaking was not consistent for all batches of rice.

The trivariate interaction, A × B × C, was not significant ($p > 0.05$). Among the 75 mean percentages the values ranged from 6.64% to 7.36%; the smaller value was associated with unsteamed samples of rough rice that had been soaked in water for 9 hours at 50°C, whereas the larger value was associated with each of two treatments, (1) unsteamed samples that had been soaked for 3 hours in water at 50°C, and (2) samples that had been soaked for 3 hours in water at 70°C and then steamed at 110°C. Fluctuations in mean values within each of the five groups ranged as follows: raw, 6.72% – 7.32%; soaked but not steamed, 6.64% – 7.36%; and for the groups steamed at 100°, 110°, and 120°C the ranges were 6.88% – 7.29%, 6.72% – 7.36%, and 6.80% – 7.32%, respectively. This indicates that, with respect to mean percentages of protein in milled rice, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were consistent for all batches of rice.

Water Uptake Ratio

The mean values for water uptake ratios of milled rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, and B × C; and the trivariate interaction, A × B × C, together with the overall mean are given in Table 7.

Among the 150 individual samples of milled rice the water uptake ratios ranged from 3.03 to 4.48, with the overall mean being 3.83. For Replicate I the mean value was 3.81; for Replicate II, 3.86. The small difference between these two means was significant ($p < 0.05$) and represented 0.05 gram of water, which corresponded to a difference of 1.8% in water content. Replicate II, as was noted in a preceding section, in comparison with Replicate I contained 1.57% more head rice in the milled product, which may account for its larger mean water uptake ratio.

The processing treatments to which the five groups of rough rice were subjected very significantly affected ($p < 0.01$) the water uptake ratios of milled rice. The mean values associated with the five treatments were: raw, 4.20; soaked but not steamed, 4.12; and for the samples steamed at 100°, 110°, and 120°C, the values were 3.84, 3.64, and 3.36, respectively. These values indicate that the soaking operation reduced the water absorption capacity of milled rice 4.3%, based on the capacity of untreated rice. Increasing the temperature of the steaming process was associated with a further reduction in water absorption capacity. The greatest reduction, corresponding to a decrease of 27.6%, occurred when the steam temperature was 120°C.

The temperature of the hot water in which the rough rice samples were soaked had a very significant effect ($p < 0.01$) on the amounts of water that were absorbed by the milled rice during cooking. Mean water uptake ratios of 3.93, 3.81, and 3.75 were associated with soaking temperatures of 50°, 60°, and 70°C, respectively. These values indicate that the 10-degree rise in temperature from 50° to 60°C was

TABLE 7.—MEANS OF WATER UPTAKE RATIOS OF MILLED RICE
(Grams of cooked rice/gram of uncooked rice)

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	4.34	4.26	4.12	4.22	3.36	4.06
	6	4.26	4.16	4.14	3.88	3.32	3.95
	9	4.36	4.14	4.11	3.82	3.26	3.94
	12	4.15	4.10	4.06	3.81	3.21	3.86
	15	4.05	4.08	4.00	3.82	3.24	3.84
60°	3	4.24	4.10	3.86	3.72	3.47	3.88
	6	4.19	4.08	3.80	3.49	3.41	3.79
	9	4.19	4.06	3.73	3.50	3.52	3.80
	12	4.21	4.20	3.72	3.55	3.47	3.83
	15	4.15	4.20	3.70	3.34	3.46	3.77
70°	3	4.19	4.07	3.91	3.62	3.43	3.84
	6	4.12	4.01	3.72	3.46	3.28	3.72
	9	4.26	4.08	3.72	3.45	3.32	3.77
	12	4.16	4.17	3.36	3.40	3.30	3.68
	15	4.16	4.12	3.62	3.42	3.42	3.75
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	4.26	4.15	3.96	3.86	3.42	3.93
	6	4.19	4.08	3.88	3.61	3.34	3.82
	9	4.27	4.10	3.85	3.59	3.37	3.84
	12	4.17	4.16	3.71	3.59	3.33	3.79
	15	4.12	4.14	3.78	3.52	3.37	3.78
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	4.23	4.15	4.09	3.91	3.28	3.93
	60°	4.20	4.13	3.76	3.52	3.46	3.81
	70°	4.18	4.09	3.67	3.47	3.35	3.75
GROUP MEANS A		4.20	4.12	3.84	3.64	3.36	OVERALL MEAN 3.83

accompanied by a decrease in absorption capacity which amounted to 0.12 gram of water per gram of rice, whereas the 10-degree rise from 60° to 70°C corresponded to a decrease of only 0.06 gram of water per gram of rice. Computed as percentages, these values indicate that the water absorption capacity of milled rice was reduced 4.1% and 2.1%, respectively, during soaking, depending on whether the temperature was increased from 50° to 60°C or from 60° to 70°C.

Increasing the elapsed time during which the rough rice was soaked in hot water very significantly ($p < 0.01$) reduced the water uptake ratio of milled rice. Soaking periods of 3, 6, 9, 12, and 15 hours were associated with water uptake ratios of 3.93, 3.82, 3.84, 3.79, and 3.78, respectively. The difference between the largest and smallest ratios, which were associated with 3 and 15 hours of soaking, respectively, represented a reduction in absorption capacity which was equivalent to 0.14 gram of water per gram of raw rice; this corresponded to a decrease of 4.8%.

Two of the bivariate interactions, A × C and B × C, were not significant ($p > 0.05$), whereas the A × B interaction was highly significant ($p < 0.01$).

In the A × B interaction, the group of untreated rough rice samples was associated with the largest ratios, which ranged from 4.18 to 4.23. Associated with unsteamed rice samples that had been soaked at 50°, 60°, and 70°C, were mean ratios of 4.15, 4.13, and 4.09, respectively. Among the three steamed groups the ratios ranged from 4.09 to 3.28; the larger value was associated with 50°C as the soaking temperature and 100°C as the steaming temperature, whereas the smaller value was associated with samples that had also been soaked at 50°C but were steamed at 120°C. This indicates that, with respect to mean water uptake ratios, the relationship between groups of samples × water temperature during soaking was not consistently maintained for all batches of rice.

In the A × C interaction, the group of untreated rough rice samples was associated with water uptake ratios that ranged from 4.12 to 4.27. The mean values for unsteamed samples that had been soaked in hot water for 3, 6, 9, 12, and 15 hours were 4.15, 4.08, 4.10, 4.16, and 4.14, respectively. Among the three steamed groups the mean ratios ranged from 3.33 to 3.96; the smaller value was associated with samples that had been soaked for 12 hours and then steamed at 120°C, whereas the larger value was associated with a 3-hour period of soaking followed by steaming at 100°C. Statistically, the A × C interaction was not significant ($p > 0.05$). This indicates that, with respect to mean water uptake ratios, the relationship between groups of samples × elapsed time during soaking was consistently maintained for all batches of rice.

In the B × C interaction, increasing either the temperature of the water in which the rough rice was soaked, or the length of time during which it was soaked, reduced the water uptake ratio of cooked milled rice. The largest value, 4.06, was associated with samples that had been soaked in water at 50°C for 3 hours, whereas the smallest value, 3.68, was associated with samples that had been soaked at 70°C for 12 hours. Statistically, the B × C interaction was not significant ($p > 0.05$). This indicates that, with respect to mean water uptake ratios, the relationship between water temperature during soaking × elapsed time during soaking was consistently maintained for all batches of rice.

In the trivariate interaction, A × B × C, the 15 untreated rough rice samples were associated with water uptake ratios that ranged from 4.05 to 4.36, with the mean being 4.20. For the samples that had been soaked in hot water but not steamed, the ratios ranged from 4.01 to 4.26; the smaller value was associated with samples that had been soaked for 6 hours at 70°C, whereas the larger value was associated with 3 hours of soaking at 50°C. For the 45 steamed samples, the ratios ranged from 3.21 to 4.22; the smaller value was associated with samples that had been soaked for 12 hours at 50°C and then steamed at 120°C, whereas the larger value was associated with 3 hours of soaking at 50°C followed by steam treatment at 110°C. In general, increasing the temperature of the steam treatment, or increasing the temperature of the water in which the samples were soaked, or increasing the elapsed time during which the samples were soaked, tended to reduce the mean water uptake ratios. The trivariate interaction was not significant ($p > 0.05$). This indicates that, with respect to mean water uptake ratios of milled rice, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were consistently maintained for all batches of rice.

Volume of Cooked Milled Rice

The volume measurements were recorded as milliliters of cooked rice that were obtained from 5 grams of uncooked milled rice which had been cooked under standardized conditions.

The mean values for volumes of cooked rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, and B × C; and the trivariate interaction, A × B × C, along with the overall mean are given in Table 8.

Among the 150 individual samples of cooked milled rice, the volumes ranged from 14.00 ml to 21.23 ml, with the overall mean being 17.62 ml. For Replicate I the mean value was 17.52 ml, and for Replicate II it was 17.72 ml. Although small, the difference between these two means was significant ($p < 0.05$).

The processing treatments to which the five groups of rough rice were subjected very significantly affected ($p < 0.01$) the volumes of cooked milled rice. The mean values associated with the five treatments were: untreated rice, 19.95 ml; rice that had been soaked in hot water but not steamed, 18.89 ml; and for the samples steamed at 100°, 110°, and 120°C, the volumes were 17.44, 16.50, and 15.32 ml, respectively. These values indicate that the soaking operation reduced the mean volume of cooked rice 1.06 ml, or 5.3%, which is in comparable agreement with the 4.3% reduction in water absorption capacity attributed in the preceding section to the soaking operation. The steaming process was associated with a further reduction in volume of cooked rice. The greatest reduction, corresponding to a decrease of 23.2%, occurred when the steam temperature was 120°C.

The temperature of the hot water in which the rough rice samples were soaked had a very significant effect ($p < 0.01$) on the mean

TABLE 8.—MEANS OF VOLUME OF COOKED MILLED RICE
(Milliliters of cooked rice from five grams of uncooked rice)

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	19.64	20.16	18.88	18.75	15.52	18.59
	6	19.26	18.76	18.58	17.90	15.53	18.01
	9	20.44	18.76	18.10	17.46	15.40	18.03
	12	20.00	18.30	18.18	17.05	15.38	17.78
	15	20.25	18.52	18.00	17.20	15.00	17.80
60°	3	19.74	18.51	17.88	17.75	15.76	17.93
	6	19.92	18.18	17.30	17.00	15.36	17.55
	9	20.02	18.75	16.95	15.62	15.81	17.43
	12	19.66	19.25	16.75	15.76	15.60	17.40
	15	20.05	18.75	16.38	15.52	15.00	17.14
70°	3	20.00	18.88	17.52	16.38	15.30	17.62
	6	19.86	19.20	17.82	15.62	14.75	17.45
	9	20.54	18.75	16.75	14.88	15.25	17.23
	12	20.25	19.25	16.50	15.50	15.15	17.33
	15	19.55	19.37	16.00	15.10	15.05	17.02
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	19.79	19.18	18.09	17.62	15.53	18.04
	6	19.68	18.71	17.90	16.84	15.22	17.67
	9	20.34	18.75	17.27	15.99	15.49	17.57
	12	19.97	18.94	17.14	16.10	15.38	17.50
	15	19.95	18.88	16.79	15.94	15.02	17.32
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	19.92	18.90	18.34	17.67	15.37	18.04
	60°	19.88	18.69	17.05	16.33	15.51	17.49
	70°	20.04	19.09	16.92	15.50	15.10	17.33
GROUP MEANS A		19.95	18.89	17.44	16.50	15.32	OVERALL MEAN 17.62

volumes of cooked milled rice. Mean volumes of 18.04, 17.49, and 17.33 ml were associated with soaking temperatures of 50°, 60°, and 70°C, respectively. These values indicate that increasing the temperature of the water in which the rough rice samples were soaked reduced the volume of the cooked rice. This, in turn, suggests that the higher the temperature of the water during the soaking operation, the longer will be the cooking time required to produce cooked rice of soft consistency.

Increasing the length of time that the rough rice samples were soaked in hot water prior to milling very significantly ($p < 0.01$) reduced the mean values for volume of cooked milled rice. The five periods of time during which the rough rice was soaked, namely, 3, 6, 9, 12, and 15 hours, were associated with mean volumes of 18.04, 17.67, 17.57, 17.50, and 17.32 ml, respectively.

Two of the bivariate interactions, A $\times$ B and A $\times$ C, were highly significant ($p < 0.01$), whereas the B $\times$ C interaction was not significant ($p > 0.05$).

In the A $\times$ B interaction, the group of untreated rough rice samples was associated with the largest volumes of cooked rice, which ranged from 19.92 ml to 20.02 ml. Associated with the unsteamed rice samples that had been soaked at 50°, 60°, and 70°C were mean volumes of 18.90, 18.69, and 19.09 ml, respectively. Among the three steamed groups the volumes ranged from 18.34 ml to 15.10 ml; the larger value was associated with 50°C as the soaking temperature and 100°C as the steaming temperature, whereas the smaller value was associated with samples that had been soaked at 70°C and steamed at 120°C. Statistically, the A $\times$ B interaction was highly significant ($p < 0.01$). This indicates that, with respect to mean volumes of cooked milled rice, the relationship between groups of samples $\times$ water temperature during soaking was not consistently maintained for all batches of rice.

In the A $\times$ C interaction, the group of untreated rough rice samples was associated with the largest volumes of cooked rice, which ranged from 19.68 ml to 20.34 ml. The mean values for the unsteamed samples that had been soaked in hot water ranged from 18.71 ml, which was associated with a 6-hour period of soaking, to 19.18 ml, which was associated with 3 hours of soaking. Among the three steamed groups of samples the mean values ranged from 15.02 ml to 18.09 ml. The larger value was associated with samples that had been soaked for 3 hours and then steamed at 100°C, whereas the smaller value was associated with 15 hours of soaking followed by steam treatment of 120°C. In general, increasing either the temperature of the steam or the length of time the samples were soaked in hot water tended to reduce the mean volume of the cooked rice. Statistically, the A $\times$ C interaction was highly significant ($p < 0.01$). This indicates that, with respect to mean volumes of cooked milled rice, the relationship between groups of samples $\times$ elapsed time during soaking was not consistently maintained for all batches of rice.

In the B $\times$ C interaction, increasing the temperature of the water in which the samples were soaked, or increasing the length of time during which the samples were soaked, tended to reduce the volume of cooked rice. The mean volumes ranged from 17.02 ml, which was associated with samples that had been soaked 15 hours at 70°C, to 18.59 ml, which was associated with 3 hours of soaking at 50°C. Statistically, the B $\times$ C interaction was not significant ($p > 0.05$). This indicates that, with respect to mean volumes of cooked milled rice, the relationship between water temperature during soaking $\times$ elapsed time during soaking was consistently maintained for all batches of rice.

In the trivariate interaction, A × B × C, the 15 untreated rough rice samples were associated with mean volumes of cooked rice that ranged from 19.26 ml to 20.54 ml, with the average for the group being 19.95 ml. The mean values for the unsteamed samples that had been soaked in hot water ranged from 18.18 ml to 20.16 ml; the larger value was associated with samples that had been soaked for 3 hours at 50°C, whereas the smaller value was associated with 6 hours of soaking at 60°C. For the 45 steamed samples the mean volumes of cooked rice ranged from 14.75 ml to 18.88 ml; the larger value was associated with samples of rough rice that had been soaked in water at 50°C for 3 hours and then steamed at 100°C, whereas the smaller value was associated with 6 hours of soaking at 70°C followed by steam treatment at 120°C. The effects of increasing the water temperature during soaking and increasing the elapsed time during soaking on reducing the mean volumes of cooked rice were less pronounced for the group of samples that had been steamed at 120°C than they were for the four other groups of samples. Statistically, the trivariate interaction was not significant ($p > 0.05$). This indicates that, with respect to mean volumes of cooked milled rice, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were consistently maintained for all batches of rice.

Total Solids in the Residual Cooking Liquid

The amount of total solids that were leached from each sample of milled rice into the water during the cooking operation was determined gravimetrically and expressed as milligrams of TSRCL (total solids in the residual cooking liquid) per gram of uncooked milled rice.

The mean amounts for TSRCL for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, and B × C; and the trivariate interaction, A × B × C, along with the overall mean are given in Table 9.

Among the 150 individual measurements, the amounts of TSRCL ranged from 21.60 mg/g to 59.00 mg/g, with the overall mean being 40.08 mg/g. For Replicate I the mean value was 39.83 mg/g, and for Replicate II it was 41.74 mg/g. The difference between these two means was highly significant ($p < 0.01$).

The processing treatments to which the five groups of rough rice were subjected very significantly affected ($p < 0.01$) the mean amounts of TSRCL. The mean values associated with the five treatments were: untreated, 48.44 mg/g; soaked but not steamed, 46.33 mg/g; and for the samples steamed at 100°, 110°, and 120°C, the amounts were 40.30, 36.04, and 32.83 mg/g, respectively. These values indicate that the soaking operation reduced the mean amount of TSRCL to the extent of 2.11 mg/g, or 4.4%. Increasing the temperature of the steaming process further reduced the mean values for TSRCL. The greatest reduction,

TABLE 9.—MEANS FOR RESIDUAL SOLIDS IN COOKING WATER OF MILLED RICE (Milligrams of residual solids per gram of uncooked rice)

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	46.10	49.05	48.05	35.95	34.05	42.64
	6	44.50	49.55	49.00	38.35	38.85	43.45
	9	48.90	49.30	52.30	40.70	37.60	45.76
	12	53.65	55.45	39.80	40.65	30.70	44.05
	15	47.40	46.90	38.70	36.30	32.80	40.42
60°	3	48.50	47.20	40.35	35.30	32.40	40.75
	6	45.20	44.45	37.50	34.60	36.05	39.56
	9	50.60	37.20	37.35	30.85	36.00	38.40
	12	49.25	46.25	36.85	33.85	36.20	40.48
	15	45.70	44.75	38.05	39.35	30.65	39.70
70°	3	47.50	42.95	40.15	37.90	32.25	40.15
	6	53.70	46.40	45.40	39.55	31.05	43.22
	9	51.25	43.70	35.30	34.45	32.15	39.37
	12	44.55	44.30	34.15	32.95	26.80	36.55
	15	49.80	47.45	31.50	29.90	27.95	37.32
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	47.37	46.40	42.85	36.38	32.90	41.18
	6	47.80	46.80	43.97	37.50	34.32	42.08
	9	50.25	43.40	41.65	35.33	35.25	41.18
	12	49.15	48.67	36.93	35.82	31.23	40.36
	15	47.63	46.37	36.08	35.18	30.47	39.15
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	48.11	50.05	45.57	38.39	34.20	43.26
	60°	47.85	43.97	38.02	34.79	34.26	39.78
	70°	49.36	44.96	37.30	34.95	30.04	39.32
GROUP MEANS A		48.44	46.33	40.30	36.04	32.83	OVERALL MEAN 40.08

corresponding to a decrease of 29.2%, occurred when the steam temperature was 120°C.

The temperature of the hot water in which the rough rice samples were soaked had a significant effect ($p < 0.05$) on the mean amounts of TSRCL. Associated with soaking temperatures of 50°, 60°, and 70°C, were mean values of 43.26, 39.78, and 39.32 mg/g, respectively. These values indicate that increasing the temperature of the water in which the rough rice samples were soaked reduced the amount of TSRCL.

The length of time that the rough rice samples were soaked in hot water did not significantly affect ($p > 0.05$) the amounts of TSRCL.

For the different periods of soaking time, namely, 3, 6, 9, 12, and 15 hours, the associated mean amounts of TSRCL were 41.18, 42.08, 41.18, 40.36, and 39.15 mg/g, respectively.

No two of the three bivariate interactions had the same degree of statistical significance. The A $\times$ B interaction was significant ($p < 0.05$); A $\times$ C was not significant ($p > 0.05$); and B $\times$ C was highly significant ($p < 0.01$).

In the A $\times$ B interaction, the group of untreated rough rice samples was associated with the largest amounts of TSRCL, which ranged from 47.85 mg/g to 49.36 mg/g. Associated with the unsteamed rice samples that had been soaked in hot water at 50°, 60°, and 70°C were mean amounts of 50.05, 43.97, and 44.96 mg/g. Among the three steamed groups the amounts ranged from 30.04 mg/g to 45.57 mg/g. The larger value was associated with 50°C as the soaking temperature and 100°C as the steaming temperature, whereas the smaller value was associated with samples that had been soaked at 70°C and steamed at 120°C. Statistically, the A $\times$ B interaction was significant ($p < 0.05$). This indicates that, with respect to mean amounts of TSRCL, the relationship between groups of samples $\times$ water temperature during soaking was not consistently maintained for all batches of rice.

In the A $\times$ C interaction, the group of untreated rough rice samples was associated with the largest amounts of TSRCL, which ranged from 47.37 mg/g to 50.25 mg/g. The mean amounts for the unsteamed samples that had been soaked in hot water ranged from 43.40 mg/g to 48.67 mg/g; the smaller amount was associated with a 9-hour period of soaking, whereas the larger amount was associated with 12 hours of soaking. Among the three steamed groups the mean amounts ranged from 30.47 mg/g to 43.97 mg/g. The larger amount was associated with samples that had been soaked for 6 hours and then steamed at 100°C, whereas the smaller amount was associated with samples that had been soaked for 15 hours followed by steam treatment at 120°C. In general, increasing either the temperature of the steam or the length of time the samples were soaked in hot water tended to reduce the mean amount of TSRCL. Statistically, the A $\times$ C interaction was not significant ($p > 0.05$). This indicates that, with respect to mean amounts of TSRCL, the relationship between groups of samples $\times$ elapsed time during soaking was consistently maintained for all batches of rice.

In the B $\times$ C interaction, the mean amounts of TSRCL ranged from 37.32 mg/g to 45.76 mg/g. The smaller amount was associated with samples that had been soaked 15 hours at 70°C, whereas the larger amount was associated with 9 hours of soaking at 50°C. Within each of the three temperature levels, 50°, 60°, and 70°C, the mean amounts of TSRCL associated with the five periods of elapsed time, namely, 3, 6, 9, 12, and 15 hours, fluctuated in different patterns. Statistically, the B $\times$ C interaction was highly significant ($p < 0.01$). This indicates that, with respect to mean amounts of TSRCL, the relationship between water temperature during soaking × elapsed time during soaking was not consistently maintained for all batches of rice.

In the trivariate interaction, A × B × C, the 15 untreated rough rice samples were associated with mean amounts of TSRCL that ranged from 44.50 mg/g to 53.70 mg/g, with the average for the group being 48.44 mg/g. The mean amounts for the unsteamed samples that had been soaked in hot water ranged from 37.20 mg/g to 55.45 mg/g. The smaller amount was associated with samples that had been soaked for 9 hours at 60°C, whereas the larger amount was associated with 12 hours of soaking at 50°C. For the 45 steamed samples the mean amounts ranged from 26.80 mg/g to 52.30 mg/g. The smaller amount was associated with samples of rough rice that had been soaked in water for 12 hours at 50°C and then steamed at 120°C, whereas the larger amount was associated with 9 hours of soaking at 50°C followed by steam treatment at 100°C. In general, increasing the temperature of the steam treatment reduced the mean amounts of TSRCL, whether the temperature of the water during soaking had been 50°, 60°, or 70°C, but increasing the elapsed time during soaking, while tending to reduce the mean amounts of TSRCL in many instances, was not infrequently associated with an increase in the mean amounts of TSRCL. Statistically, the trivariate interaction was significant ($p < 0.05$). This indicates that, with respect to mean amounts of total solids in the residual cooking liquid from milled rice, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were not consistently maintained for all batches of rice.

Optimum Conditions for Complete Gelatinization

In parboiled rice the presence of ungelatinized kernels lowers the quality of the milled product. The degree of gelatinization is affected by three variables in the parboiling process, namely, (1) temperature of the hot water in which the rough rice is soaked, (2) length of elapsed time during which the rough rice is soaked, and (3) temperature of the steam treatment.

The presence of "white belly," which is apparent when rice kernels are examined under a strong fluorescent light, is an indication that the rough rice had been insufficiently subjected to the combined effects of moisture and heat to produce complete gelatinization of the starch granules in rice kernels.

Earlier reports by Bhattacharya et al. (*7*) and Mecham et al. (*41*) are in accord with the observation here reported that increasing the temperature of the water in which the rough rice was soaked reduced the elapsed time necessary to effect complete gelatinization of the starch in the kernels.

The results of examining the kernels for the presence of "white belly" indicated that, for rough rice that had been soaked in water at 50°C, increasing the steam temperature from 100°C to 110°C had little or no effect on the optimal number of hours, 9 to 12, of soaking that was associated with complete gelatinization of starch in the kernels, whereas for rough rice soaked in water at 60°C and steamed at either 100° or 110°C, the optimal number of hours of soaking was 6 to 9, which was reduced to 3 to 6 hours by increasing the steam temperature to 120°C.

These relationships are indicated in the outline below:

OPTIMAL SOAKING PERIOD (HOURS)

SOAKING WATER TEMP. (°C)	STEAM TEMPERATURES (°C)		
	100°	110°	120°
50°	9-12	9-12	6-9
60°	6-9	6-9	3-6
70°	3-6	3-6	<3

SUMMARY AND CONCLUSIONS

Newly harvested, long-grain rough rice of the Dawn variety was obtained from the Rice Experiment Station, Crowley, Louisiana. Samples of this grain were parboiled under controlled conditions. The effects of four variables, namely,

(a) two replicate experiments,
(b) five group treatments that involved untreated rice, rice that had been soaked in hot water but not steamed, and rice that had been soaked in hot water and then treated for 10 minutes with steam at 100°C, at 110°C, and at 120°C,
(c) three levels of temperature, 50°, 60°, and 70°C, of the water in which the rough rice was soaked, and
(d) five periods of elapsed time, 3, 6, 9, 12, and 15 hours, during which the rough rice was soaked in water,

on eight selected qualities and characteristics of milled rice gave sets of laboratory data pertaining to: total yield of milled rice, percent of head rice in the milled product, color of milled rice, protein content of brown rice, protein content of milled rice, water uptake ratio of milled rice, volume of cooked milled rice, and residual solids in cooking water.

A total of 150 300-gram batches of rough rice were prepared. The separate batches were stored in closed polyethylene bags at 40°F until they were used.

After the samples had been soaked and steamed under the appropriate conditions, they were dried at room temperature until the moisture content was 12% as measured by means of a Motomco electric moisture tester. They were stored in new polyethylene bags at room temperature until they were milled.

Exactly 150 grams of rough rice from each sample was taken and shelled in a McGill sheller. The samples of brown rice thus obtained were kept in polyethylene bags that were stored at 40°F until they were milled in a Satake Testing Pearler, Model OM–2B. The milled rice was weighed and the total yield of milled product was computed. The samples of milled rice were individually placed in separate polyethylene bags that were stored at 40°F.

The milled rice samples were assayed for head rice by means of a Grain Sizing Device. Final separation of the broken kernels from the head rice, or unbroken kernels, was made manually, grain by grain. The samples of head rice were placed in polyethylene bags and stored at 40°F until they were used in the color, protein, and cooking tests.

The color of the milled rice was measured by means of a Gardner Digital Color and Color Difference Meter, Model X–10, with L, a, and b scales. Only whole kernels were used in the color measurements. The sample was read against a reference White Reflectance Standard No. 1093 which was supplied by the manufacturer.

The protein content was computed from the nitrogen values that were obtained by analyzing aliquots of the brown and milled rice samples by the Kjeldahl method.

The cooking test was carried out in a glass tube containing 50 milliliters of distilled water and 5 grams of rice; the tube and contents were immersed in boiling water for 20 minutes. The gruel was strained through a sieve, and after removing excess moisture the cooked rice was weighed to obtain the water uptake ratio. The volume of the cooked rice was determined by the water displacement method. The gruel was evaporated to dryness in a tared beaker; the content of residual solids was determined by gravimetric methods.

Each of the eight variables measured was evaluated according to a $5 \times 3 \times 5$ factorial arrangement of treatments in a randomized block design with 2 replicates ($A \times B \times C \times R$, where A represents group treatment that included 3 levels of steam temperature; B, soaking temperature; C, elapsed time during soaking; and R, replicates). The data for each variable were subjected to a standard analysis of variance for a mixed model in which A was regarded as a fixed effect and B and C were random effects. The major findings of these analyses are outlined below.

Total Yields of Milled Rice

The results of the analysis of variance indicated the following regarding total yields of milled rice:

(1) There was a significant difference between the two replicate means, which were 68.97% and 69.40%. In the experiments the samples in the two replicates were milled about a week apart. The higher yield is probably associated with a degree of milling that was slightly less than that associated with the smaller yield.

(2) The temperature of the water during soaking had a significant effect. Total yields of 69.02, 69.09, and 69.45% were associated respectively with water temperatures of 50°, 60°, and 70°C. Increasing temperature of the soaking water gave small increases in total yields.

(3) The length of time during which the rough rice was soaked in hot water had no significant effect; however, there was a tendency for samples that had been soaked 6 hours or longer to give slightly higher total yields than samples that had been soaked for only 3 hours.

(4) Steaming the rough rice after soaking had a significant effect, but the soaking operation alone had no significant effect. Total yields of 65.71% and 65.64% were associated respectively with untreated rice and rice that had been soaked but not steamed; total yields of 71.55, 71.49, and 71.53% were associated respectively with steam temperatures of 100°, 110°, and 120°C. The steaming operation itself increased the total yield about 6%, but increasing the temperature of the steam had no effect.

None of the interactions of the effects of soaking temperature × soaking time, soaking temperature × steam temperature, and soaking time × steam temperature were significant. The effects of the trivariate interaction, soaking temperature × soaking time × steam temperature, were significant.

Yields of Head Rice

The results of the analysis of variance indicated the following regarding yields of head rice:

(1) There was a significant difference between the two replicate means, which were 80.91% and 82.48%. This finding is in agreement with a similar finding for the replicate means for total yields of milled rice.

(2) The temperature of the water during soaking did not have a significant effect. There was a tendency, however, for increased yields of head rice to be associated with elevated soaking temperatures. Head rice yields of 80.31, 80.70, and 84.08% were associated respectively with water temperatures of 50°, 60°, and 70°C.

(3) The length of time during which the rough rice was soaked in hot water had a significant effect. The yield of head rice increased until the soaking time reached 9 hours. No advantage was gained by extending the soaking time beyond 9 hours. Associated with the five periods of soaking time, 3, 6, 9, 12, and 15 hours, were head rice yields of 75.22, 81.05, 84.35, 83.86, and 84.00%, respectively.

(4) The group treatments that included three levels of steam temperature had significant effects. Head rice yields of 75.18% and 64.42% were respectively associated with untreated rice and rice that had been soaked but not steamed. The effect of the soaking operation was to reduce the yield of head rice nearly 11%. The steaming operation greatly increased the yield of head rice to 87.14, 90.31, and 91.42%,

respectively, for steam temperatures of 100°, 110°, and 120°C. The beneficial effect of the steaming operation was attributed to the gelatinization and hardening of the kernels under the moist influence of elevated steam temperatures.

The interactions of the effects of soaking temperature × soaking time, soaking temperature × steam temperature, and soaking time × steam temperature were highly significant, and the trivariate interaction, soaking temperature × soaking time × steam temperature, was significant.

Color of Milled Rice

The results of the analysis of variance indicated the following regarding the color values of milled rice:

(1) Replication had no effect on the mean color values, which were almost identical for the two replicates, 31.71 and 31.72.

(2) The temperature of the water during soaking had a highly significant effect. Color values of 29.62, 31.87, and 33.65 were associated respectively with water temperatures of 50°, 60°, and 70°C. Increasing the temperature of the soaking water caused the color of the milled product to become darker.

(3) The length of time during which the rough rice was soaked in hot water had a highly significant effect. The color of the milled product darkened by stages until the soaking time reached 12 hours; extending the soaking time to 15 hours did not affect the color. Associated with the five periods of soaking time, 3, 6, 9, 12, and 15 hours, were color values of 29.56, 31.10, 31.74, 33.07, and 33.09, respectively.

(4) The group treatments that included three levels of steam temperature had significant effects. Color values of 21.37 and 25.05 were respectively associated with untreated rice and rice that had been soaked but not steamed. The effect of the soaking operation was to darken the milled product, and the steaming operation darkened the color still further as indicated by the three color values 33.82, 37.35, and 40.97 that were associated respectively with steam temperatures of 100°, 110°, and 120°C.

The interactions of the effects of soaking temperature × soaking time, soaking temperature × steam temperature, and soaking time × steam temperature, and the trivariate interaction, soaking temperature × soaking time × steam temperature, were highly significant.

Protein Content of Brown Rice

The results of the analysis of variance indicated that replication had no effect on the mean values of protein content, which, for the two replicates of 75 samples each, were 8.24% and 8.22%. Likewise, the temperature of the soaking wate., the length of soaking time, and the steam temperature had no significant effects on the protein content of brown rice.

Protein Content of Milled Rice

The results of the analysis of variance indicated that replication had no effect on the mean values of protein content, which, for the two replicates of 75 samples each, were 7.11% and 7.13%. Similarly, the temperature of the soaking water, the length of soaking time, and the steam temperature had no significant effects on the protein content of milled rice.

Water Uptake Ratio of Milled Rice

The results of the analysis of variance indicated the following regarding water uptake ratios of milled rice:

(1) There was a significant difference between the two replicate means, which were 3.81 and 3.86. The difference between these two values represented 0.05 gram of water and corresponded to a difference of 1.8% in capacity to absorb water. This finding of a significant difference between replicate mean values for water uptake ratio is in agreement with similar findings for replicate means of total yields of milled rice and yields of head rice.

(2) The temperature of the water during soaking was highly significant. Water uptake ratios of 3.93, 3.81, and 3.75 were associated respectively with soaking water temperatures of 50°, 60°, and 70°C. Increasing the temperature of the water in which the rough rice was soaked reduced the water uptake ratio of the milled product.

(3) The length of time during which the rough rice was soaked in hot water was highly significant. Associated with the five periods of soaking time, 3, 6, 9, 12, and 15 hours, were water uptake ratios of 3.93, 3.82, 3.84, 3.79, and 3.78, respectively. The maximum reduction in values occurred after 15 hours of soaking, and it was equivalent to 0.15 gram of water; this represented a 5.1% decrease in the capacity of the milled product to absorb water.

(4) The group treatments that included three levels of steam temperature were highly significant. Water uptake ratios of 4.20 and 4.12 were respectively associated with untreated rice and rice that had been soaked but not steamed. The effect of the soaking operation was to reduce the water uptake ratio. The steaming operation further reduced the water uptake ratios to 3.84, 3.64, and 3.36, respectively, for steam temperatures of 100°, 110°, and 120°C. The reduced values indicate that soaking the rough rice in hot water reduced the water absorption capacity of the milled product 4.3% relative to the capacity of untreated rice and that, furthermore, soaking in hot water followed by steaming at 120°C effected a reduction of 27.6%.

The interactions of the effects of soaking temperature × soaking time, soaking time × steam temperature, and the trivariate interaction, soaking temperature × soaking time × steam temperature, were not significant. The interaction of the effects of soaking temperature × steam temperature was highly significant.

Volume of Cooked Milled Rice

The results of the analysis of variance indicated the following regarding the volumes of cooked milled rice:

(1) There was a significant difference between the two replicate means, which were 17.52 ml and 17.72 ml. This finding is in agreement with similar findings for water uptake ratios, yields of head rice, and total yields of milled rice.

(2) The temperature of the water in which the rough rice was soaked was highly significant. Volumes of 18.04, 17.49, and 17.33 ml were associated respectively with soaking water temperatures of 50°, 60°, and 70°C. Increasing the temperature of the water in which the rough rice was soaked reduced the volume of the cooked milled product. This finding suggests that the higher the temperature of the water during soaking, the longer will be the cooking time required to produce cooked rice of soft consistency.

(3) The length of time during which the rough rice was soaked in hot water was highly significant. Associated with the five periods of soaking time, 3, 6, 9, 12, and 15 hours, were cooked milled rice volumes of 18.04, 17.67, 17.57, 17.50, and 17.32 ml, respectively. Increasing the length of the soaking time reduced the volume of the cooked milled rice.

(4) The group treatments that included three levels of steam temperatures were highly significant. Cooked milled rice volumes of 19.95 ml and 18.89 ml were respectively associated with untreated rice and rice that had been soaked but not steamed. The effect of the soaking operation was to reduce the volume of the cooked milled rice. The steaming operation further reduced the volumes to 17.44, 16.50, and 15.32 ml, respectively, for steam temperatures of 100°, 110°, and 120°C.

The interactions of the effects of soaking temperature × soaking time, and the trivariate interaction, soaking temperature × soaking time × steam temperature, were not significant. The interactions of the effects of soaking temperature × steam temperature, and soaking time × steam temperature, were highly significant.

Residual Solids in Cooking Water

The results of the analysis of variance indicated the following regarding the residual solids in cooking water:

(1) There was a highly significant difference between the two replicate means, which were 39.83 and 41.74 milligrams of residual solids per gram of uncooked milled rice. This finding is in agreement with similar findings for replicates for volumes of cooked milled rice, water uptake ratios, yields of head rice, and total yields of milled rice.

(2) The temperature of the water in which the rough rice was soaked was significant. Residual solids in the cooking water amounting to 43.26, 39.78, and 39.32 mg/g were associated respectively with soaking water temperatures of 50°, 60°, and 70°C. Increasing the temperature

of the water in which the rough rice was soaked reduced the amount of residual solids in the cooking water.

(3) The length of time that the rough rice was soaked in hot water was not significant. There was a tendency, however, for smaller amounts of solids in the cooking water to be associated with longer periods of soaking time. Associated with the five periods of soaking time, 3, 6, 9, 12, and 15 hours, were respectively, in milligrams of solids per gram of uncooked milled rice, 41.18, 42.08, 41.18, 40.36, and 39.15 mg/g.

(4) The group treatments that included three levels of steam temperature were highly significant. The residual solids in the cooking water amounted to 48.44 mg/g and 46.33 mg/g, respectively, for untreated rice and rice that had been soaked but not steamed. The soaking operation slightly reduced the amount of solids in the cooking water. The steaming operation further reduced the amounts to 40.30, 36.04, and 32.83 mg/g, respectively, for steam temperatures of 100°, 110°, and 120°C.

The interaction of the effects of soaking time × steam temperature was not significant. The interaction of the effects of soaking temperature × soaking time was highly significant, whereas that of soaking temperature × steam temperature was significant, as was also the trivariate interaction, soaking temperature × soaking time × steam temperature.

Optimal Length of Soaking Period

The optimal length of the soaking period necessary to bring about complete gelatinization of starch in rice kernels ranged from 9 to 12 hours to less than 3 hours, depending upon the soaking temperature and the steam temperature. The longer periods were associated with rough rice that had been soaked at 50°C and then steamed at either 100° or 110°C, whereas the shortest period of optimal soaking time was associated with samples of rough rice that had been soaked at 70°C followed by treatment with steam at 120°C.

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